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US 4015552

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(54) Minimum heave offshore structure

(57) The facility includes a deck 16 mounted on buoyant support columns 32, a space frame 52 mounted below the support columns, and a base structure 78 which includes ballasted pontoons mounted at the lower end of the space frame 52 at a draft below the principle wave action zone. The configuration of the unit provides passive means to compensate for part of the dynamic response from external forces. Active means of compensation is accomplished by a riser tensioner system. Additional active means are provided to compensate for the quasi-static response of the facility to tidal variations and the riser draw-down due to steady state wind, current and wave driven effect of the facility relative to the reference position on the sea bed.

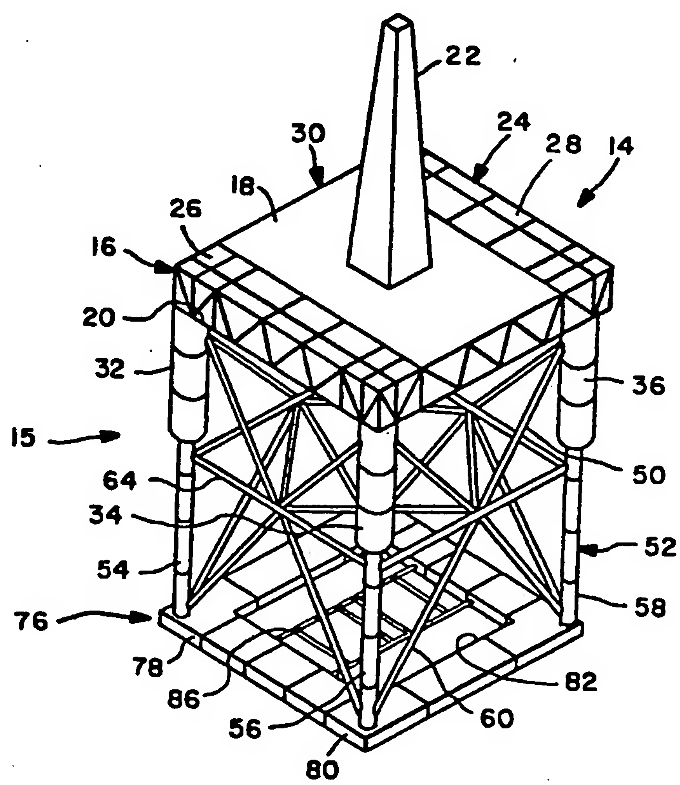

FIG.—2

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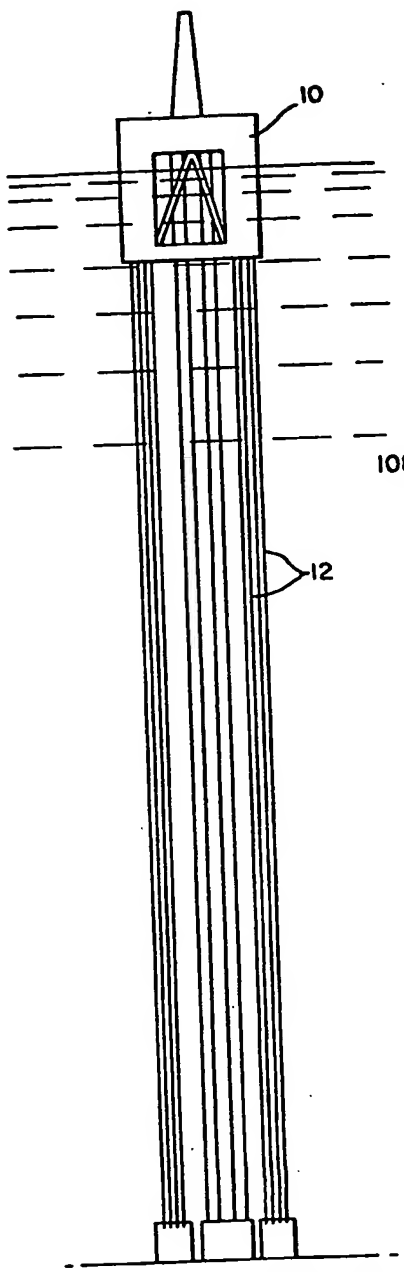

FIG.—1

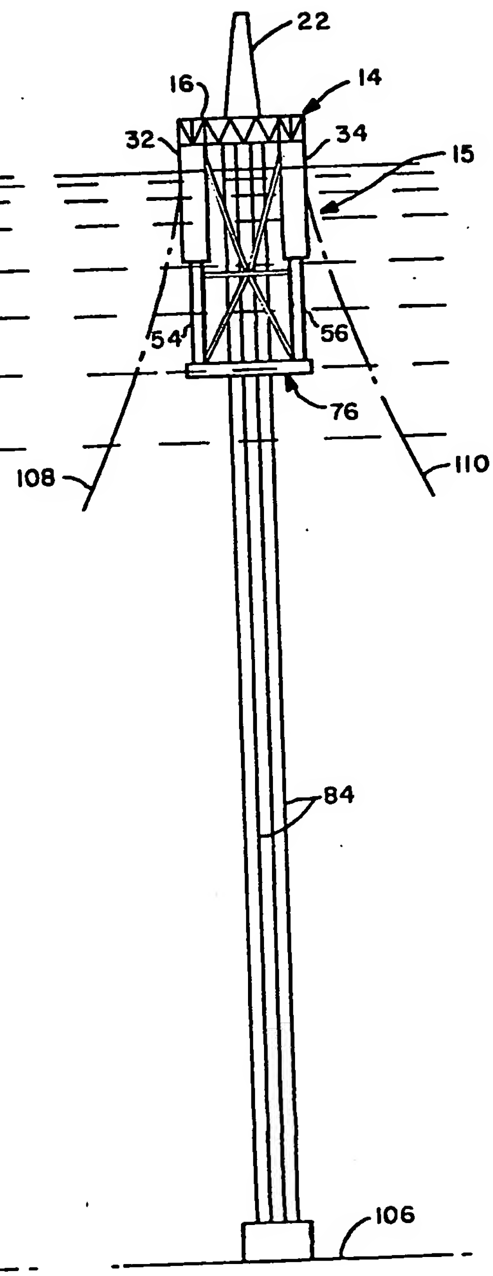

FIG.—8

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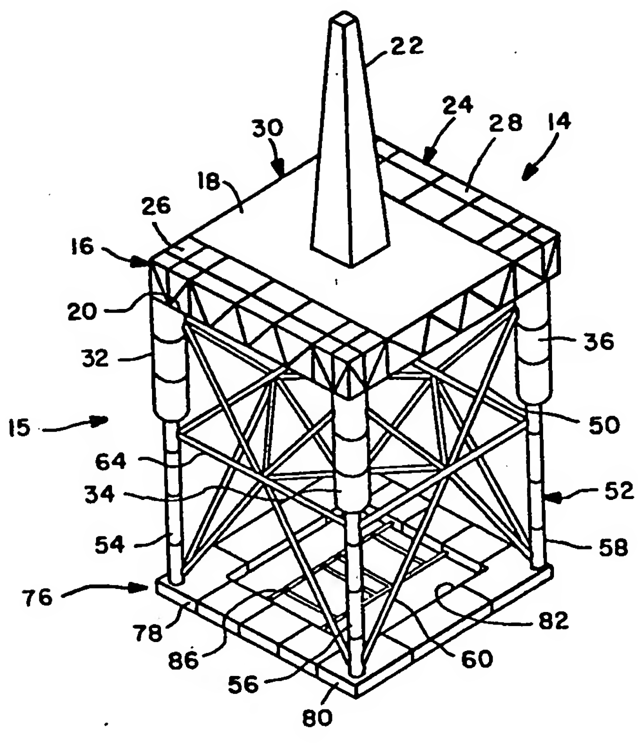

FIG.—2

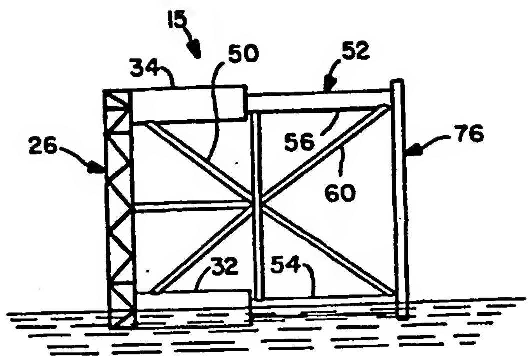

FIG.—3

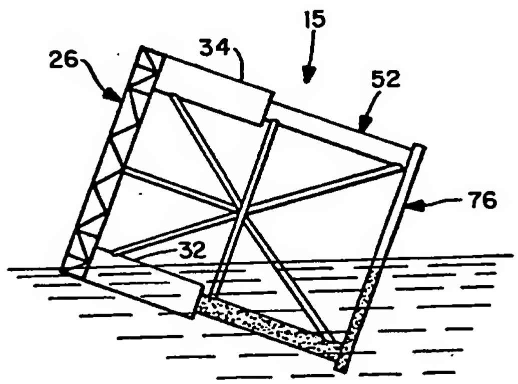

FIG.—4

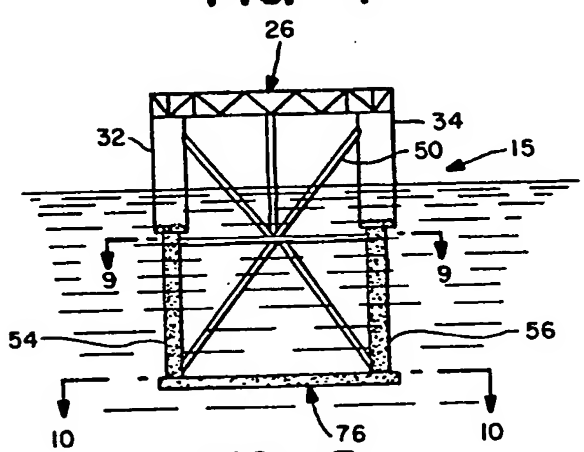

FIG.—5

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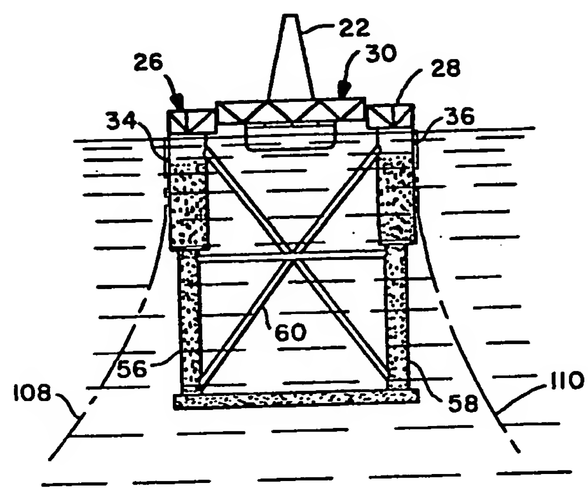

FIG.—6

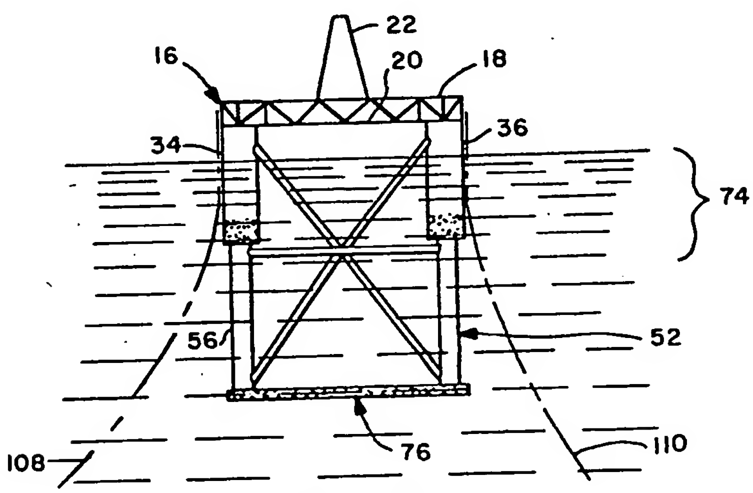

FIG.—7

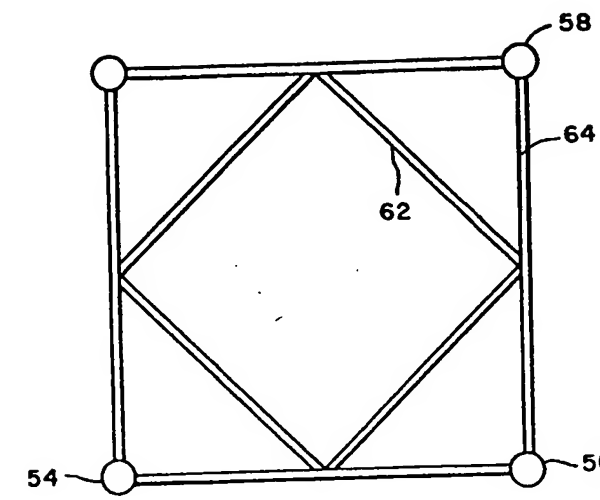

FIG.—9

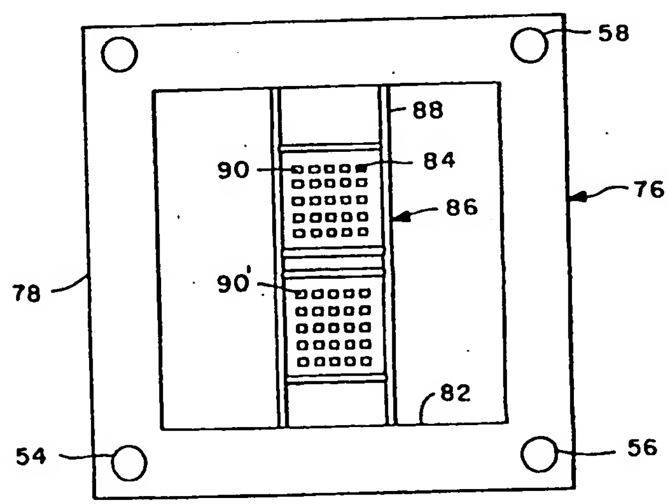

FIG.—10

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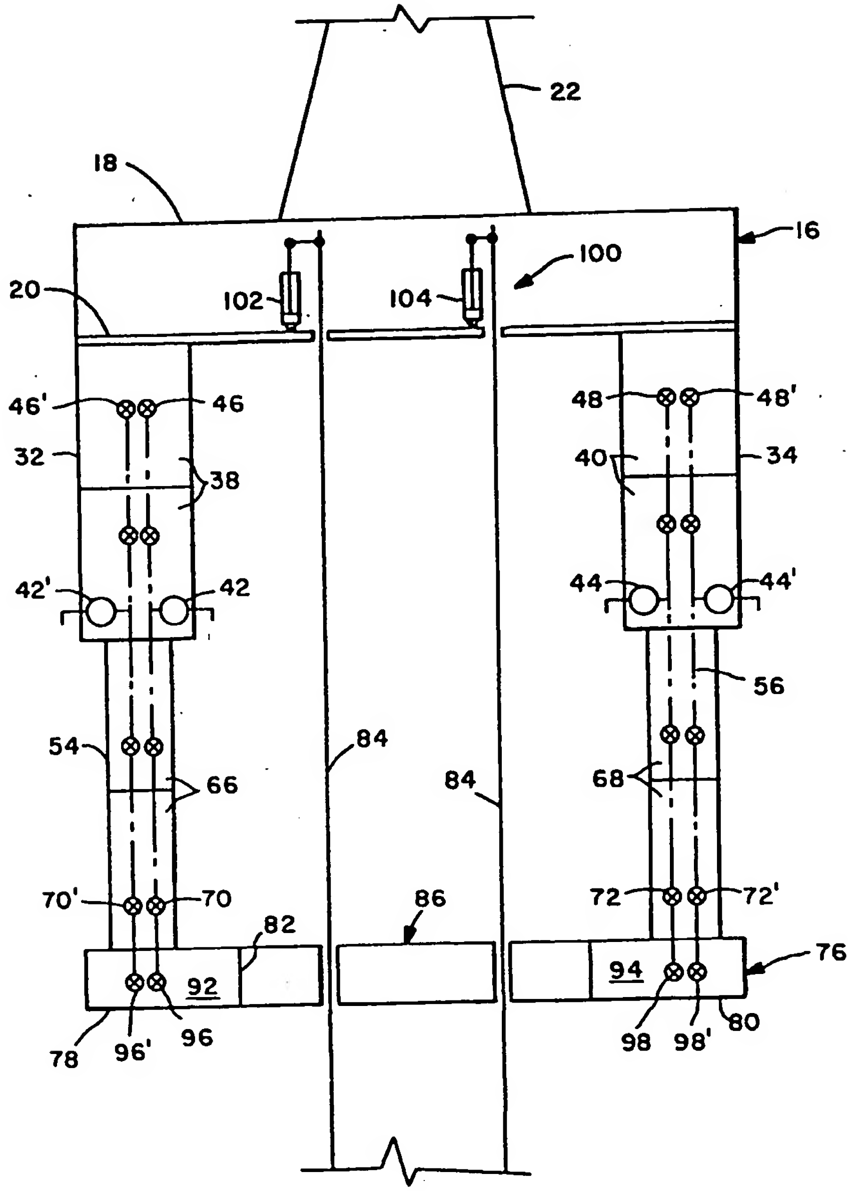


FIG.—11

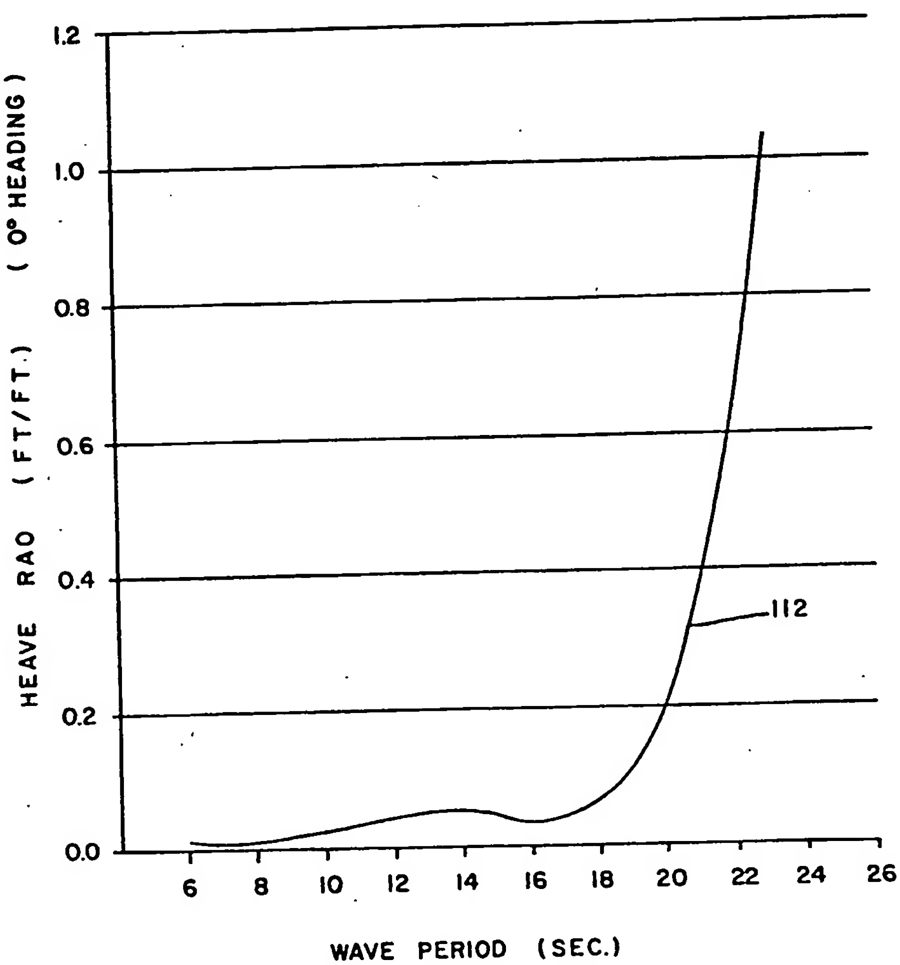
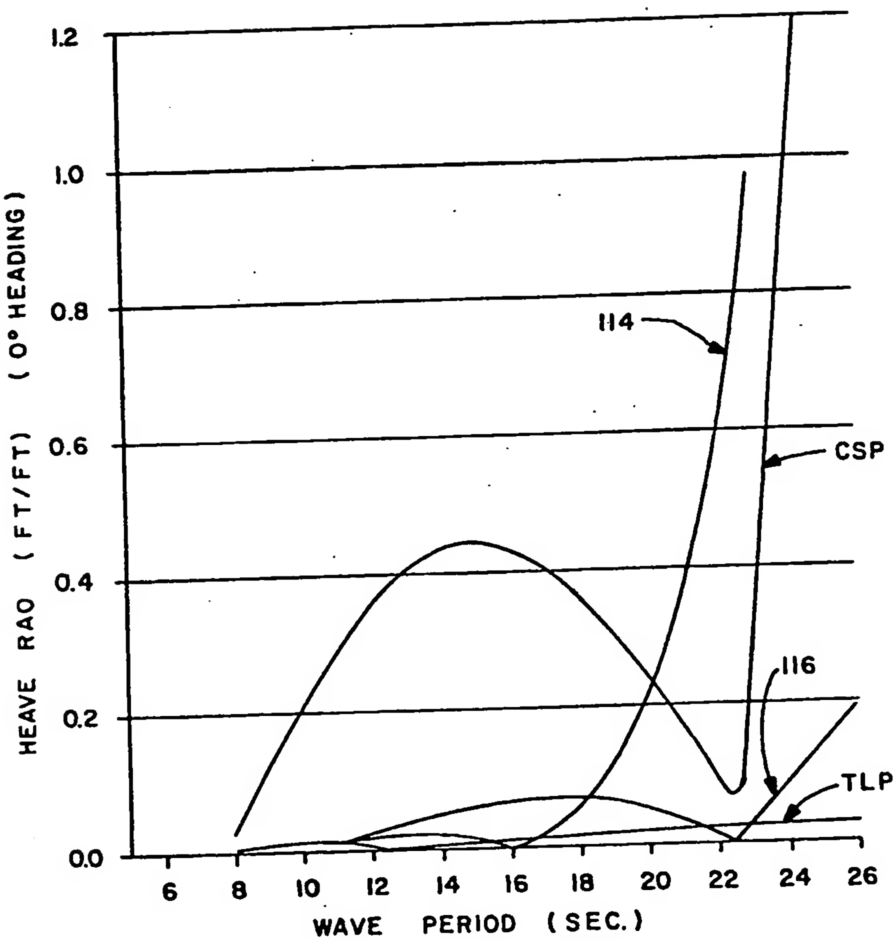

HEAVE RAO (FT/FT.) (0° HEADING)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
6
8
10
12
14
16
18
20
22
24
26
112
WAVE PERIOD (SEC.)

FIG.—12



1.2
1.0
0.8
0.6
0.4
0.2
0.0
HEAVE RAO (FT/FT) (0° HEADING)
6
8
10
12
14
16
18
20
22
24
26
WAVE PERIOD (SEC.)
114
CSP
116
TLP

FIG.—13

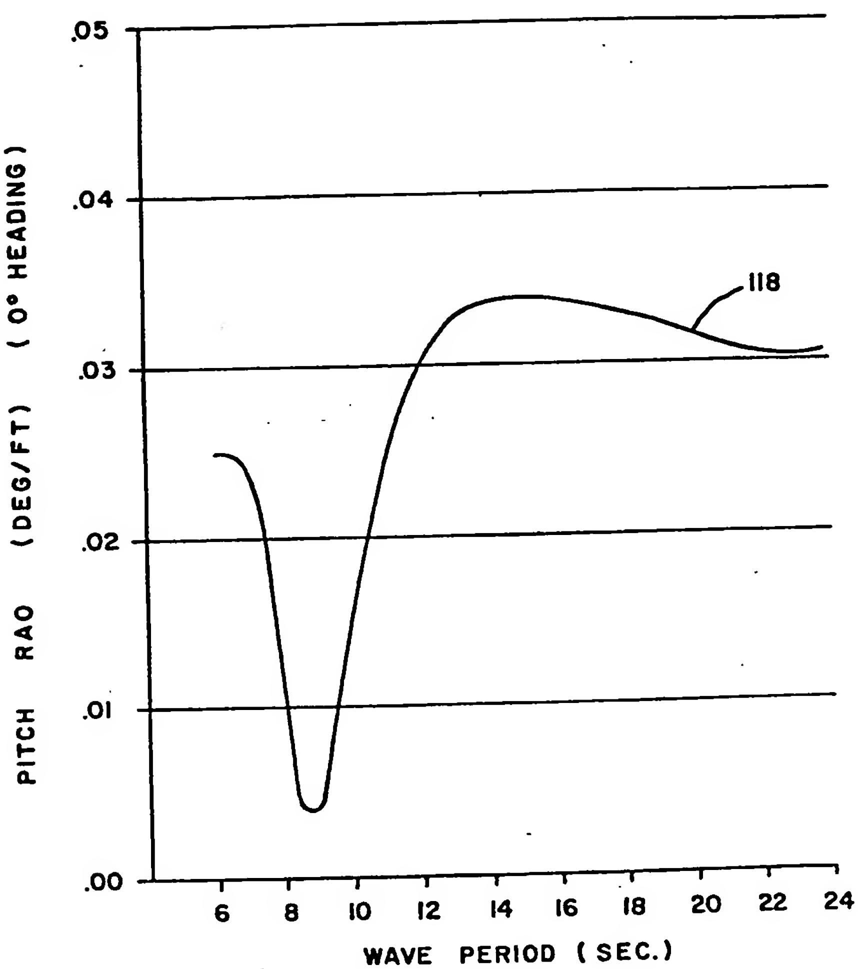

.05
.04
.03
.02
.01
.00
PITCH RAO (DEG/FT) (0° HEADING)
118
6
8
10
12
14
16
18
20
22
24
WAVE PERIOD (SEC.)

FIG.—14

SPECIFICATION

Floating facility

This invention relates to floating facilities for use in deep water offshore operations such as oil and gas exploration, drilling and production as well as radar stations and the like where it is desired to maintain a stable platform in a relatively fixed position over the sea bed.

Previously various offshore platform designs and configurations have been developed for deep water applications where the cost of a fixed structure becomes prohibitive. These prior designs, all of a compliant nature, include guyed towers which extend upwardly from a foundation on the sea bed for supporting a drilling floor, wellhead floor or other platform above the water level. Another prior system incorporates a floating vessel with a ship shape form having a central opening or moonpool through which pipe risers extend from a drilling deck downwardly into the sea bed. Another prior system termed a column stabilized platform includes a lower submersible hull which supports an upper deck by means of vertical buoyancy columns. Yet another prior design, known as a tension leg platform, is of the configuration shown in Fig. 1. In the tension leg platform system the upper platform includes a buoyant vessel 10 from which a plurality of tethers 12 extend down to the sea bed. Tension forces are applied to the tethers by buoyant forces on the vessel, providing stability. In the tension leg platform system, changes in buoyancy such as tidal variation or passing waves increase or decrease tension on the risers.

Offshore platforms of the guyed tower or tension leg platform types are relatively expensive to build. Floating platforms of conventional ship shape hull designs are highly vulnerable to extremes of wind, current and wave action, which causes severe heave, pitch and roll motions and typically these vessels must decouple from the risers to ride out relatively small storms. Column stabilized platforms are characterized in having significantly better motions in wave action than the ship shape vessels, but not nearly as good as the guyed tower or tension leg platform.

The invention provides floatable structure for offshore operations in deepwater, including a support element to be maintained above sea level, and a deep draft element to remain below the principal wave zone and oppose vertical heave by hydrodynamic resistance (i.e. virtual mass).

The invention also provides a facility for use in deepwater offshore operations, comprising a deck structure, support columns mounted below the deck structure with their axes generally vertical to provide partial buoyancy to support the deck structure above the water, a skeletal frame fixed below the support columns with a lower portion of the skeletal frame extending to a draft below the principal wave zone at which draft there is minimal water partical acceleration due to wave action, and a base structure fixed to that lower portion of the skeletal frame, said base structure having a substantial projected area in a horizontal plane providing a substantial virtual mass which combines with the effective mass of the base structure to resist vertical acceleration of the facility in response to evnironmental forces.

In the above description of the invention the terms "below", "vertical", "above", "lower" and "horizontal" refer to the facility when it is floating upright in deep water.

The invention in summary includes a floating facility comprised of a deck structure supported on upright columns which can be ballasted and deballasted. The support columns carry a space frame the lower end of which mounts a base structure of relatively large virtual mass at a depth below the principal wave zone to achieve a low dynamic heave response. A riser tensioning system and ballast system provide active compensation for dynamic and static responses to environmental forces. Major components of the facility can be fabricated at a shore location and towed to destination for final assembly and mooring at the desired station over the sea bed.

Specific embodiments of the invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 is an elevational view of one type of prior art tension leg platform system.

Figure 2 is a perspective view of a floating facility incorporating the present invention.

Figure 3 is an elevational view of the facility of Fig. 2, without deck, showing the unit configured for floating on its side for towing to destination at a deep water location.

Figure 4 is an elevational view of the facility similar to Fig. 3 during an initial stage of flooding of ballast compartments for rotation of the unit toward its upright orientation.

Figure 5 is an elevational view of the facility similar to Fig. 4 illustrating a further rotational position of the unit toward its upright orientation.

Figure 6 is an elevation view at right angles to Fig. 5 illustrating a stage of final assembly in which the unit is ballasted deeper in the water and a subassembly of the deck structure is towed on a barge into alignment for assembly with the jacket at the upper end of the unit.

Figure 7 is an elevational view of the facility similar to Fig. 6 illustrating the operating draft and ballast conditions with mooring lines in place.

Figure 8 is a side elevational view of a

floating facility in operating configuration moored at its station and coupled with pipe risers leading to the sea bed.

Figure 9 is a cross-sectional view taken along the line 9–9 of Fig. 5.

Figure 10 is a cross-sectional view taken along the line 10–10 of Fig. 5.

Figure 11 is a schematic drawing of the facility of Fig. 2 illustrating the riser tensioning means and the ballasting system.

Figure 12 is a graph illustrating equivalent platform heave RAO relative to a riser as a function of wave period for one example of the invention.

Figure 13 is a graph illustrating platform heave RAO as a function of wave period for one example of the invention.

Figure 14 is a graph illustrating platform pitch and roll RAO as a function of wave period for one example of the invention.

In the drawings Figs. 2–10 illustrate generally a* 14 a floating facility or platform constructed in accordance with one embodiment of the invention. Floating facility 14 includes a deck structure 16 of truss girder construction and a supporting substructure 15 comprised of columns, space frame and base structure. For an oil and gas drilling and production configuration the deck structure preferably includes an upper deck 18 which provides a drilling floor for supporting the drilling and production equipment and supplies, and a lower deck 20 which provides a wellhead floor for surface completion of the wells. Conventional christmas tree connections, not shown, on the wellhead permit ready access for maintenance on the platform. A derrick 22 is mounted on the facility above the upper deck.

The components of deck structure 16 include perimeter truss girders 24 having spaced-apart side sections 26 and 28 between which a deck subassembly 30 is mounted (Fig. 6). As explained hereafter, the jacket and deck subassembly are preferably fabricated separately at a shore location and then floated and towed to a deep water destination where they are assembled together.

Support means for the deck structure comprises a plurality, (preferably four) of upright, large diameter cylindrical support columns 32, 34 and 36. The support columns are mounted below and circumferentially spaced about the deck structure, and in the illustrated embodiment the columns are positioned at respective corners of the rectangular deck to provide wide spacing for improved stability. Each of the columns are of hollow shell construction provided as shown in Fig. 11, with internal ballast compartments 38, 40 together with sea pumps 42, 44, valves 46, 48, and suitable valve controls, not shown, for selectively ballasting and deballasting the individual columns. The columns are of relatively large diameter to provide buoyancy and stability for the facility and the heavy equipment and supply loads which it carries as well as the drawdown forces from the pipe risers. A pair of the columns on one side of the facility further provide buoyancy which supports the unit on its side for towing to destination. On each of the four sides bracing members 50 are mounted between the columns.

A space frame 52 is mounted below the support columns and comprises upright cylindrical legs or columns 54, 56, 58, each of which extends coaxial with a respective one of the support columns. The space frame further includes bracing members 60 mounted between the legs across each of the sides as wells cross-braces 62, 64 mounted in a horizontal plane at the upper end of the four legs, as shown in Fig. 9. Ballast compartments 66, 68 are provided in each of the legs of the space frame and the sea water pumps 42, 44 valves 70, 72 and suitable valve controls, not shown, are associated with each of the legs for selective ballasting and deballasting. With the facility moored to its operation draft as shown in Fig. 7 the lower ends of the space frame legs extend to a depth below the principal wave zone, illustrated approximately at 74 in Fig. 7. At that depth below the principal wave zone there is minimal water particle acceleration and velocity so that vertical forces from wave action acting on the lower portions of the facility are also at a minimum. In addition, the lower space frame and base structure provide minimal projected surface area, giving reduced lateral response to wave action, i.e., the lower portions of the facility are relatively transparent to wave action.

A base structure 76 is mounted at the lower ends of the space frame columns. The base structure includes a perimeter pontoon structure comprising pontoons 78, 80 mounted about a central opening 82 through which the risers 84 extend, as best illustrated in Fig. 10. The pontoons are provided with ballast compartments which are flooded in the operating mode of the facility. The base is supported by the space frame at a deep draft such that the mass of the base when the pontoons are flooded causes the centre of gravity of the facility to be at an elevation such that a positive metacentric height of sufficient magnitude is achieved to provide good stability. The large mass and virtual mass of the base and flooded pontoons further resist acceleration of the facility from external forces.

The opening 82 through the pontoons of the base structure is bridged by a horizontally extending riser guide unit 86. The riser guide unit is comprised of a frame 88 which supports an array of well slots 90 each of which is adapted to support a riser laterally. The riser guide restrains the risers at pontoon level against lateral movement relative to the facility.

Preferably two ballast systems are provided

for purposes of redundancy. Thus, at the bottom of each column as shown in Fig. 11 two pumps 42, 42′ and 44, 44′ having a high capacity rating are provided. As an example, the provision of ballast pumps in each column rated at 2,500 gpm capacity can achieve, with four pumps in operation, a response of 9 ft. change in draft per hour. The ballast control system is operable to ballast and deballast each of the four columns separately, so to compensate for trim angle changes such as due to load shifting on the deck, or for required draft changes. Ballast compartments 92, 94 are formed in the pontoons and the sea water pumps 42, 44, valves 96, 98 and suitable valve controls, now shown, are provided to ballast and deballast the pontoons. Ballast pumping for the pontoons, as well as ballast pumping for the space frame legs 54, 56, if required, could be provided by suitable ballast pumps separate from the pumps for the main support columns.

Riser tensioning means 100 (Fig. 11) is provided within deck 16 for maintaining a relatively constant tension on the risers. Preferably the riser tensioning means comprises double acting hydraulic or pneumatic power cylinders 102, 104 which are connected with upper ends of the risers 84. The stroke of the power cylinders for a particular application would depend on the range of displacement from maximum expected heave. For example, a stroke of the order ± 5 ft. might be provided for the power cylinders where the facility operates in the 1,500–2,000ft range of water depth. A suitable hydraulic/pneumatic control system, not shown, is provided to extend and retract the power cylinders as required to maintain the riser tension relatively constant for accommodating relative vertical movement between the deck and risers due to heave, pitch, platform offset and riser curvature.

Means is provided for holding/mooring facility 14 in station-keeping position at the desired location over the seabed 106. Preferably the mooring means includes a catenary anchored system comprising a plurality of lines 108, 110 connected to and spreading away from the four corners of the facility. The lines can comprise a combination of wire rope and chain connected with anchors or piles at the seabed.

Specific examples of the use and operation of the invention are as follows. As a first Example I a floating facility is constructed in accordance with Figs. 2–10 sized and proportioned to carry topsides payload, equipment and fuel weight of 12,000 short tons (ST) and with anchorline tension of 1,000 ST, riser tension of 3,000 ST, platform structure weight of 20,000 ST, support column equipment of 500 ST and ballast of 22,000 ST with a total displacement of 58,500 ST. The dimensions of this example are 200′ between centres of the support columns on each side, a 300 ft. operating draft and with 50′ freeboard to the underside of the deck.

A second Example II is a floating facility constructed in accordance with Figs. 2–10 designed for a topsides payload, equipment and fuel weight of 21,000 ST, anchorline tension of 1,000 ST, riser tension of 3,000 ST, platform structure weight of 28,000 ST, a support column equipment weight of 500 ST and ballast of 27,500 ST, giving a total displacement of 81,000 ST. Dimensions of the facility of the example include 300′ spacing between support column centres on each each side, operating draft of 350′ and 50′ freeboard to the underside of the deck.

Construction of the floating facility will be explained in connection with Example II. Construction of the substructure jacket 15 begins at a suitable onshore yard or graving dock by fabrication, erection and assembly of the pontoons, bracing members, space frame, support columns and side sections of the deck jacket with the assembly oriented on its side, similar to the position shown in Fig. 3. All ballast tanks are deballasted and additional buoyancy, as required, can be provided by securing additional pontoons, removable tanks or a submersible barge to the structure's frame. The facility substructure is launched from skidways pontoon end first in the longitudinal direction or floated out of a graving dock.

With the facility substructure jacket 15 in a floating position as illustrated in Fig. 3 it is towed to destination at the desired deep water location where final assembly procedure begins. Controlled flooding of the ballast compartments in the pontoons as well as the lower legs of the space frame, as illustrated by the solid sectioning of Fig. 4, initiates sinking and rotation of the facility. During the next stage of rotation the ballast compartments of the upper pontoon sections are flooded when they penetrate the water's surface, and the upper space frame legs are also flooded bringing the unit to the vertical orientation illustrated in Fig. 5. As shown in Fig. 6 the restraining mooring lines 108, 110 are connected to the facility and anchored to the sea bed.

Next, the ballast compartments of the support columns are flooded sufficient to sink the facility to the minimum freeboard illustrated in Fig. 6. The central section or subassembly 30 of the deck is separately constructed and commissioned at an on-shore location, moved by a barge or other vessel to the final assembly location, and towed through the middle of the jacket as illustrated in Fig. 6. The deck subassembly is aligned with opposite sides 26, 28 of the jacket and the support columns are then deballasted to raise the jacket in alignment with the deck. After the deck subassembly and jacket are secured to-

gether the support columns are deballasted further to permit removal of the barge. The facility can then be ballasted to bring it to the desired freeboard. Additional mooring lines, as required, are then added and the drilling or other operation can proceed.

During drilling the pipe risers extend from the deck down through riser guide unit 86 to the sea bed. The operating draft and ballast configuration are illustrated in Fig. 7. In this configuration the space frame legs are deballasted, the pontoons are completely flooded, and a controlled amount of ballast is maintained in the support columns for compensation of the heave caused by the tidal change.

During operation the floating facility of the invention is characterized in achieving a relatively low heave response. Heave motion is a function of the platform's hydrostatic stiffness, the forces acting on the platform and its natural period, the latter being a function of hydrostatic stiffness and effective mass. The motions response of a floating platform can be analyzed as comprising two components. The first is the dynamic response resulting from the higher frequency excitations of waves. The second is the quasi-static response resulting from the lower frequency excitations of tide, current and wind. In the invention these motions are compensated for by passive and active means respectively. The passive means of compensation for dynamic response is provided primarily by the novel configuration of the invention, namely the sizing, placement and spacing of the pontoons, space frame, support columns and deck structure. The relatively small diameters of the space frame legs and members present minimal area to wave action, and the space frame supports the pontoons at a draft below the principal wave zone where there is minimal water particle acceleration, thereby minimizing vertical heave forces on the unit. The relatively large diameter support columns and their wide horizontal spacing further enhances stability of the facility.

An active means of heave compensation is required for the risers as a result of dynamic heave motions caused by the components of platform heave, pitch, roll, surge and slow drift. This active means of compensation for the dynamic riser response comprises the riser tensioning system 100 depicted in Fig. 11. In Fig. 12 the plot line 112 depicts the platform heave RAO (Response Amplitude Operator) as a function of wave period for the outermost riser 84 position in the well slot array of Fig. 10. The maximum platform heave RAO relative to the riser in the 12–15 second range for storm wave periods is 0.04. For a sixty ft. maximum storm wave, this will give a double amplitude heave of 2.4 ft. Added to this is an anticipated one ft. draw-down on the riser for the dynamic portion of the platform offset caused by surge and drift. The total dynamic platform heave amplitude relative to the risers is therefore of the order of 4 ft.

An additional active means to compensate for the quasi-static heave component of platform motions response is required. This active compensation is accomplished with the trim ballast system of the facility. Assuming a maximum storm wave induced tidal range of 10 ft. and a 2 ft. riser draw-down resulting from the steady state offset of the facility from current and wind, a total quasi-static heave range of 12 ft. is compensated for by operating the ballast system in the support columns. Trim angle changes such as resulting from variable deck loads are compensated for by selectively ballasting and deballasting the four support columns.

The invention contemplates an alternate active means for static heave compensation by means, not shown, of mounting the wellhead floor for vertical movement with respect to the deck structure. Preferably this means would include a jacking system engaging tracks mounted at each of the four corners of the moveable wellhead floor which is driven up and down by a suitable electric or hydraulic system, not shown.

The low heave response resulting from floating facilities according to Example I and Example II are compared in the graph of Fig. 13 with the heave responses plotted in comparison to a comparable tension leg platform (TLP) as well as a typical prior art column stabilized platform (CSP). The chart depicts heave RAO (response amplitude operator) as a function of wave period. In the wave period range below 17 seconds, the maximum heave RAO is 0.02 for Example I (plot line 114) and the maximum heave RAO is 0.07 for Example II (plot line 116).

In Fig. 14 plot line 118 depicts the pitch (and roll) RAO as a function of wave period for the facility according to Example I of the invention.

CLAIMS

1. A facility for operation in water, comprising the combination of a deck structure for supporting a load, support column means mounted upright below the deck structure for providing partial buoyancy to support the deck structure and load above the water, a space frame mounted below the support column means with the lower end of the space frame extending to a draft where there is minimal water particle acceleration below the principal wave zone, a base structure mounted on the lower end of the space frame with the base structure having a substantial projected area in a horizontal plane providing a substantial virtual mass which combines with the effective mass of the base structure to resist vertical acceleration of the facility from external forces.

2. A facility as claimed in Claim 1 in

which the space frame is of cylindrical configuration comprised of a plurality of legs interconnected by truss members which present minimal surface area to the action of water particle acceleration in the zone of wave action, said base structure mass and draft placement providing passive compensation for at least a portion of the dynamic response from higher frequency excitations of wave action acting on the facility.

3. A facility as claimed in Claim 1 or Claim 2 which includes means for providing active heave compensation for at least a portion of the dynamic response from higher frequency excitations of wave action on the facility.

4. A facility as claimed in Claim 3 for use in suspending pipe risers leading to the sea bed for oil and gas exploration, drilling and production operation, in which the means for providing active compensation includes tensioning means carried on the facility for applying tension forces to the risers with the tension forces being controlled to compensate for dynamic heave motions relative to the riser resulting from platform heave, pitch, roll, surge and slow drift movements.

5. A facility as claimed in any one of the preceeding Claims which includes means for providing active compensation for at least a portion of the quasi-static response from lower frequency excitations of tide, current and wind action on the facility.

6. A facility as claimed in Claim 5 in which the means for providing the active compensation includes means for ballasting and deballasting the facility.

7. A facility as claimed in Claim 6 in which the means for ballasting and deballasting includes ballast compartments formed in the support column means.

8. A facility as claimed in Claim 6 in which the base structure includes pontoon means positioned about the perimeter of the lower end of the space frame, and the means for ballasting and deballasting includes ballast compartments formed in the pontoon means.

9. A facility as claimed in any one of the preceeding Claims for use in suspending pipe risers leading to the sea bed for oil and gas exploration, drilling and production operation, said base structure including a perimeter pontoon structure having a central opening through which the risers extend.

10. A facility as claimed in Claim 9 together with riser guide means carried by the pontoon structure and extending across the opening for restraining the upper ends of the risers against lateral movement with respect to the facility.

11. A facility as claimed in any one of the preceeding Claims in which the deck structure includes one or more floor structures for carrying drilling and production equipment, together with a substructure having opposite deck truss sides mounted across upper ends of the support column means with these deck trusses supporting the main deck structure whereby during installation this main deck structure can be separately constructed, floated to destination and assembled to the opposite sides of the jacket structure.

12. A facility as claimed in any one of the preceeding Claims for use in supporting pipe risers leading to the sea bed for oil and gas exploration, drilling and production operations, in which the support column means comprises a plurality of cylindrical columns circumferentially spaced about the perimeter of the deck structure with the columns spaced about the risers whereby buoyancy of the columns provides stability and support for the facility and the risers.

13. A facility as claimed in any one of the preceeding Claims which includes ballast compartments in each of the columns separately receiving and discharging sea water to provide at least partial compensation for the quasi static heave component of forces acting on the facility and also to provide trim compensation for variations in load on the deck.

14. A facility as claimed in any one of the preceeding Claims which includes mooring means for holding the facility at a selected position on the water surface above the seabed.

15. A facility as claimed in any one of the preceeding Claims which includes means forming ballast compartments in both the support column means and the pontoon structure, and means for selectively changing ballast in the ballast compartments to provide buoyancy for floating the facility on its side with the support columns in a horizontal orientation for movement of the facility through the water and to provide buoyancy for floating the facility with the columns oriented upright with the deck structure having freeboard above the surface of the water.

16. A facility as claimed in Claim 15 in which the space frame includes cylindrical legs extending below the support column means, means forming ballast compartments in the legs, and means for selectively changing ballast in the ballast compartments of the legs.

17. Floatable structure for offshore operations in deepwater, including a support element to be maintained above sea level, and a deep draft element to remain below the principal wave zone and oppose vertical heave by hydrodynamic resistance (i.e. virtual mass).

18. A facility for use in deepwater offshore operations, comprising a deck structure, support columns mounted below the deck structure with their axes generally vertical to provide partial buoyancy to support the deck structure above the water, a skeletal frame fixed below the support columns with a lower portion of the skeletal frame extending to a

draft below the principal wave zone at which draft there is minimal water partical acceleration due to wave action, and a base structure fixed to that lower portion of the skeletal frame, said base structure having a substantial projected area in a horizontal plane providing a substantial virtual mass which combines with the effective mass of the base structure to resist vertical acceleration of the facility in response to environmental forces.

19. A facility substantially as hereinbefore described with reference to and as shown in Figs. 2–7 and 9–11, and in Fig. 8 of the accompanying drawings.

20. A method of constructing a facility substantially as hereinbefore described with reference to Figs. 2–7 of the accompanying drawings.

CLAIMS

Amendments to the claims have been filed, and have the following effect:–

Claims 17 above have been deleted or textually amended.

New or textually amended claims have been filed as follows:–

17. Floatable structure for use in deepwater and including a deck, wherein buoyancy for the structure is provided by a plurality of horizontally spaced support means, and vertical heave resistance is provided by the virtual mass of a base having substantial projected area in a horizontal plane disposed beneath and spaced apart from said support means to remain sufficiently below the principal wave zone to have low heave response due to avoidance of wave excitation, such that the functions of buoyancy and heave resistance are separated.

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